SESSION TWELVE: SMALL SOLAR SYSTEM BODIES

The Christmas Comet of Johann Palitzsch

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Gary A. Becker

At this moment the world awaits the triumphant return of Palitzsch's Comet, one of the most celebrated astronomical events viewed throughout recorded history. Every return of this comet to the inner solar system has been chronicled as far back as 239 BCE. This object has probably been viewed by more eyes than any other transient wanderer of the solar system.

The comet's biographical profile and its influence upon the aspirations of humanity is every more fascinating than its longevity. Comet Palitzsch was the sword which hung over the city of Jerusalem at the start of the Jewish revolt against Rome in 66 AD. It appeared during the year that Attila the Hun was defeated by Roman and Visigoth legions in the battle of Chalons-sur-Marne, France (451 AD). The demoralizing effects of the sudden appearance of Palitzsch's comet in March, 1066, may have caused King Harold's army to succumb to the invading forces of William the Conqueror at the Battle of Hastings. Later, in 1456, Pope Callistus III, frightened by the comet's presence and war with the Turks, "mandated public prayers for several days in order to avert God's wrath, and in the cities he ordered that bells be run, so that everyone would be reminded about the prayers to be recited…"

Unfortunately, the great excitement over the 1986 return of Halley's Comet has cloaked Johann Palitzsch's discovery in a shroud of smoky vapors. The truth is that both comets are really one and the same, and although the famed English astronomer Edmond Halley (1656-1742) figures prominently in its history, the comet was really misnamed. It was actually discovered by a very keen-sighted German amateur, Johann Georg Palitzsch (11 June 1723—22 February 1788) of Prohlis, Saxony. It should be his name that we associate with the comet and not Halley's.

With few exceptions the name which a comet receives is the same as that of the person or persons who first observes and recognizes the object as a comet. There can be as many as three names attached to the comet if it is independently discovered by as many different individuals in fairly rapid succession. This tradition has been regulated by international agreement and represents the most familiar of the three methods by which a comet can be named. The comet we associate with Edmond Halley, however, is an anomaly to this procedure, and has created an historical amnesia as far as Johann Palitzsch's work is concerned. Palitzsch was the amateur stargazer who initially observed the comet at the time of its predicted return. For Palitzsch's efforts and his lifelong passion for the heavens, a little-remembered, elongated crater near the eastern limb of the moon was name in his honor. Why then was Halley so successful in attaching his own name to a comet that should have rightfully belonged to Johann Palitzsch?

The story of Edmond Halley is one of personal successes and fortunes which would make any individual living in the twenty-first century envious. Among dozen of glittering accomplishments, Halley was the first to chart the southern skies, to explore rigorously the Earth's magnetic field, and to prove conclusively that comets orbited the sun. He was a scientific prodigy who, in almost any other period of time would have been proclaimed as the greatest example of human intellect. Yet this was not Halley's epoch. He was only a "second-rate" genius, whose intellectual capabilities were eclipsed in the astonishing brilliance of Isaac Newton (1643-1727). Palitzsch may have been denied the acknowledgment which he deserved because of Halley's close association with Newton, a name that was almost synonymous with invincibility in the scientific community.

The two men, Newton and Halley, were of totally different dispositions, yet they were on the best of terms with each other. Halley could be described as extroverted, adventurous, witty in conversation, and atheistically inclined. Newton was cunning, introverted, God-fearing, and like a child with a special gift, afraid to share its joys with others. Strange bedfellow indeed, but their mutual respect and unpretentiousness provided each other with even greater opportunities for achievement than could have been attained by each one acting alone.

Halley supplied the coaxing, and then the funding, for one of science's greatest books, Newton's ***Principia Mathematica***. Within the pages of its first section, Newton explained his unification of the heavens and the Earth. He provided the first clear explanation of how gravity acted throughout space to bind the matter of the universe under one set of laws which could explain the motion of all objects. This led Halley to his most memorable scientific accomplishment, the verification which proved Newton's gravitational theory to be universal in character.

A small part of the ***Principia*** involved comets, tiny snowballs composed of ices and dust, which in prominent examples, developed long gossamer tails as they approached the sun. Their physical constitution was not known in Newton's time; nor would it be revealed for another two centuries until the advent of the spectroscope and the development of quantum mechanics. Comets simply appeared mysteriously, in some cases brightened spectacularly, then slowly dimmed to invisibility several weeks or months later. Because so little was knows about them, they were cloaked in mystery and superstition; their ghostly tails were magnified by the imagination into twitching daggers which menaced both heaven and Earth, kings and commoners alike. Even Newton at first was unsure of how to incorporate them into his cosmological schemes.

A bright comet had made an appearance in November of 1680, and was visible before the sun rose. Then after a period of invisibility, it was observed after sunset. The observations were interpreted by Newton and others as resulting from two distinctly separate comets passing the sun in parabolic trajectories. In a dissenting opinion, John Flamsteed, Astronomer Royal of England, proposed that the comets of 1680 were actually one and the same object, observed before and after reaching its closest position to the sun.

The implication here was that the motion of a comet was predictable and logically influenced by the sun's gravitational force. Flamsteed had lucidly detailed his ideas with a careful series of observations, but Newton was still unimpressed. The impasse between them lasted for nearly five years, but in the end it was Newton who uncharacteristically yielded and reluctantly accepted Flamsteed's argument, writing in the first edition of the ***Principia*** (1687) that comets were subject to the same laws of gravitation as the planets. Newton was suggesting the possible existence of elliptical orbits, closed elongated paths, which would one day return the comets back to their fiery tormentor.

The development of Halley's ideas regarding comets paralleled those of his good friend Newton. He had originally presumed their movements to be parabolic in nature, but like Newton, Halley had also opted for the probability of other types of motion. His reasoning contained an interesting mixture of good scientific procedure and unrestrained speculation.

Halley felt that the frequency of cometary discoveries being made by astronomers of his day was too great to be only attributed to new comets approaching the sun for the first time. Some of them had to be repeated passages of the same objects, and therefore revolving around the sun in elliptical orbits. He inferred this from observations which demonstrated that some comets moved in hyperbolic orbits with "a Motion Swifter than what a Comet might acquire by its Gravity to the Sun…" Since astronomers were only observing a very small portion of the comet's path near the sun, the comet's true orbital shape was being slightly altered by its close proximity to the planets. If the orbit of the comet could be observed in its entirely, it would resemble a very eccentric ellipse.

By defining the movement of a comet through the solar system in three dimensions, the similarity of orbits could be easily deduced upon its next return to the sun. Such comets could be identified as periodic in nature. Halley wrote:

> …we may be able to know, by comparing together the Elements, whether it be any of those which has appear'd before, and consequently to determine its Period, and the Axis of its Orbit, and to fortel[l] its Return. And, indeed there are many things which make me believe that the Comet which Apian observ'd in the year 1531, was the same with that which Kepler and Longomontanus more accurately describ'd in the Year 1607; and which I myself have seen return, and observ'd in the Year 1682. All the Elements agree, and nothing seems to contradict this my opinion…

Edmond Halley then went on to make this famous prediction.

> Hence I think I may venture to foretel[l] that it will return again in the Year 1758. And, if it should then so return, we shall have no reason to doubt but the rest may return also…

Halley died in 1742 at the age of 86, but his hypothesis of the return of a bright comet continued to stimulate the interests and expectations of the scientific community. Realizing that he would be over 100 years of age when the comet was scheduled to reappear, and fully comprehending the improbability of such longevity, Halley wrote that "if it (the comet) should return according to our prediction about the year 1758, impartial posterity will not refuse to acknowledge that this was first discovered by an Englishman"

The time was Christmas night, 1758. Thirty-five-year-old Johann Georg Palitzsch, a self-educated Saxony farmer living in Prohlis near the larger town of Dresden, decided to conduct one of his regular observations of the starry heavens. For many years Palitzsch had been building a local reputation as a perceptive thinker and amateur astronomer. He was, however, unable to shake the burdensome demands of the small farm which he managed by himself. His philosophical pursuits were merely his spare time pleasures; and they included astronomy, mathematics, physics, and botany. He was a collector of objects of natural history and maintained a garden which had achieved notoriety because it contained some of the most exotic varieties of planets. This evening, though, his concerns were elsewhere.

Foremost on his mind was his reflecting telescope and how he would safely transport the cumbersome apparatus outdoors, away from the farm building. He had built it himself, casting grinding, and polishing a small mirror from brittle speculum metal. In contrast to the tiny mirror, the wooden tube was eight feet long, making the telescope and its rectangular mounting support difficult to move.

Starlight was gathered by a spherically shaped mirror located near the bottom of the tube and reflected to a second, flat mirror, which diverted the converging cone of light through a hole near the upper end of the instrument. Today these telescopes are called Newtonian reflectors in honor of Isaac Newton, who constructed the first small prototypes nearly a century earlier.

Palitzsch moved the telescope form his dwelling to a small grassy parcel of frozen ground. He faced the reflector south against the starry backdrop of the fall constellations. Pegasus, Andromeda, Cetus, Pisces, and Aquarius were located in front of him. Orion was preparing for a stellar climb over the eastern horizon. Cygnus, looking more like a crucifix than a swan protecting the west. It was a fitting reminder of the importance of the season.

The time was six o'clock, and already the chilled air was beginning to numb his fingers. Johann's body shivered against the sharp gusts of wind which easily pierced his garments. But the sky dazzled his imagination. His keen vision raced to bring order to the glittering luminaries which danced in silence above his head. Little did he realize how special tonight was going to be.

The telescope was shifted toward the constellation of Cetus the Sea Monster. The eyepiece was carefully placed in its holder, and Palitzsch began a routine observing session, examining the brighter stars of this pattern. He was particularly interested this evening in observing the variable star Mira Ceti. The star's brightness varied on average by nearly six magnitudes, an intensity factor greater than 200, and for several months each year it was visible to the unaided eye.

Palitzsch continued to sweep the heavens, slowly swiveling the telescope westward by about 20 degrees into the constellation of Pisces the Fish, now straddling the meridian in the south. As he scanned some of its brighter luminaries near the border of Cetus, he spotted a previously unseen fuzzy object between the fourth magnitude stars Delta and Epsilon Piscium. Aware that the target might be a new comet, and possibly the one predicted by Halley, Palitzsch recorded its position and then eagerly awaited the evening of December 26th.

For the stalwart Palitzsch, the daylight hours of December 26th must have been full of anticipation and emotional unrest. At that moment he was the sole guardian of a secret that had to be kept from the rest of the world. Palitzsch waited for the mid-afternoon sunset and for a reenactment of the previous night's observations.

The weather remained clear on the 26th, and the object was again spotted after sundown, but this time slightly shifted to the northwest of its original location. Confident that he had observed a new comet, Palitzsch communicated by letter with a professional colleague and friend, Dr. Christopher Gotthold Hofmann in Dresden and announced his discovery. The correspondence was received by Hofmann on the 27th, and he immediately acted upon the information, confirming Palitzsch's disclosure with a much smaller three foot telescope at eight o'clock that same evening. Hofmann viewed the comet on the subsequent night, noting its northwestward motion as Palitzsch had indicated.

Johann Palitzsch's discovery of what is now called Halley's Comet was not by accident. He had carefully studied the most recent prediction calculated by the French mathematician, Alexis Clairaut (1713-1765). Palitzsch had also been making a concerted effort to search for the comet that Edmond Halley had suggested would return about his time. What was indeed remarkable about his find was that Palitzsch had succeeded in winning the competition against some of the best professional astronomers in Europe, who were also searching for the comet, and who were much better equipped to recover it first. To their embarrassment, Palitzsch's discovery came four weeks prior to the next independent sighting, which was make by the great French astronomer and comet seeker, Charles Messier (1730-1817). Messier sighted the comet on January 21, 1759. He had been jealously anticipating that he would win the competition to see it first, and rightfully so, for his search had been in progress for about 18 months.

The first published announcement of Palitzsch's find occurred the day before Messier independently saw the comet. Hofmann wrote an article which appeared in the second part of the ***Dresden Scholarly Announcement of 1759*** under the title, "Report of the Comet which has been seen since the 25th of December." Curiously enough, the document made no claim that this was the comet predicted by Halley over one-half century earlier.

It appears that Hofmann was playing it safe, for he realized that so small a body as a comet would be easily influenced by the gravitational fields of the planets, and hence it could be substantially delayed in its return. Already European astronomers had been fooled twice in announcing that Dr. Halley's comet had returned. One of these visitors was observed in the fall of 1757, while the other was seen just a few months earlier during the summer of 1758.

Viewing the situation with hindsight, Palitzsch and Hofmann must have suspected the comet to be Halley's, for they had clearly established its retrograde nature. Up until the present only four periodic comets have been discovered to display this type of orbital motion, which is opposite to the direction of movement of the planets. In 1759, however, the periodicity of comets had not yet been established, so such an assumption may have been inappropriate. In addition, Hofmann may simply have not possessed sufficient mathematical skills to calculate an orbit from the observational data. Certainly Palitzsch's talents were not up to such a task.

Unfortunately for Palitzsch, the scientific community took Halley's advice and chose to "…acknowledge that this was first discovered by an Englishman." The find became known as Halley's Comet. The extraordinary efforts of the very vigilant Johann Palitzsch were thus relegated to the fine print of footnotes in nineteenth century texts and all but forgotten in recent years.

It is interesting to speculate what Palitzsch's future would have been like had he received a larger proportion of the credit for his cometary discovery. Greater prestige may have allowed him the opportunity to solicit financial support which could have given him the freedom to pursue his hobbies on a more regular and professional basis. That is exactly what happened to the Englishman William Herschel (1738-1822), a musician by profession, but an astronomer by avocation, who 22 years after Palitzsch's discovery, found a "comet" which in turn revealed itself to be the planet Uranus. Herschel's fame spread like wildfire throughout Europe, and via the lobbying efforts of a well-positioned friend, he was able to obtain the post of Royal Astronomer to King George III. Released form the toil of his musical commitments, Herschel went on to become the most famous astronomer of his era and perhaps the most prolific observer of the nighttime sky for all times.

It does not seem that Johann Palitzsch received any of the prestigious advantages afforded to others who made discoveries of similar magnitude. He continued to manage his small farm until a stroked ended his life in 1788 at the age of 64. During this time, he because a corresponding member of the academies of London and St. Petersburg and continued to augment his beautiful collection of natural history objects. Astronomical observations were also a priority, and it was here again that contributions made by this Saxony farmer went unrecognized. Two examples will follow.

In 1782, John Goodricke (1764-1786), the deaf-mute son of an English diplomat, determined the period of the well-known variable star, Algol (Beta Persei) as two days, 20 hours, 49 minutes. Goodricke contended that the diminution of light from Algol resulted from the partial eclipse of a dark companion revolving around the primary star. Johann Palitzsch independently determined the period of the same star in 1783, “by means of original observations made by himself.” It is not known, however, whether Palitzsch attempted to explain the mechanism of variability as the young Goodricke had done. Goodricke’s reward for his labors resulted in his receiving the Copley Medal from the Royal Society in London and his induction into that learned society just two weeks prior to his death, from exposure, at the age of 21.

Two years earlier, in the spring of 1780, a newspaper account credited Palitzsch with the discovery of yet another comet, this time in the constellation of Cancer the Crab. Within days it was realized that he had erred, mistaking a cluster of yellowish stars which his small telescope could not resolve, for the warm, diffuse glow of a comet just beginning to blossom.

Ironically his rival, Messier, catalogued this same cluster of stars as the 67th object in an ongoing list of nebulae that he was compiling. Their accurate location, he hoped, would prevent them from being mistaken for new comets when observed through a small telescope. Messier’s discovery was recorded on April 6, 1780. Although he did credit his French contemporary, Pierre Mechain (1744-1805), with first observing dozens of other objects which were later entered into his catalogue; it appears that Messier claimed priority for M67, which was undoubtedly first seen by Palitzsch. Perhaps Messier felt justified in overlooking Palitzsch’s discovery because of his dismal failure, 21 years earlier, to secure the winning position in the unofficial race to become the first observer to view the predicted return of Halley’s Comet. Palitzsch, however, was victorious on both accounts.

It would be fascinating to know how many other significant contributions Johann Georg Palitzsch made during his part time career as an amateur scientist. The true historical record of his accomplishments may be like a lustrous crystalline gem, with the many facets of his existence now left difficult to authenticate because of a lack of documentation and the erosion of time.

A. Anatomy of a Comet: "Comets are like cats**;** they have tails**,** and they do precisely what they want." -David H. Levy. A comet is the closest thing to nothing that anything can be and still be considered something (anonymous).
   1. Nucleus: Dirty snowball
      a. Solid part of the comet

   b. Composed mostly of water ice, with smaller amounts of carbon dioxide, carbon monoxide, ammonia, methane, and trace amounts of organic molecules.
   c. Very small and irregularly shaped—usually less than 10 miles along its longest axis
   d. Density much less than water (one), similar to a loosely packed snowball.
   e. Little structural integrity—easily broken apart.
   f. The nucleus has a surface of dust several inches thick under which pockets of gas can form when the nucleus is warmed by the sun.

2. <u>Coma</u>: Fuzzy head of the comet
   a. Region of space immediately surrounding the nucleus
   b. Pockets of sublimating gases "pop" through the thin shell of the nucleus releasing the trapped gasses and dust which they contain
   c. The dust and gas begin to surround the nucleus in an ever expanding volume.
   d. The nucleus and coma can be called the head of the comet.
   e. The coma is the brightest region of the comet.

3. <u>Ion tail</u>: Shaped by the sun's magnetic field and emits its own light (fluoresces)
   a. The straight blue tail of a comet. The ion tail has a cone-shaped structure pointing directly away from the sun
   b. Ultraviolet light from the sun ionizes the gases creating plasma composed of electrons, ions, and free radicals. The gas also fluoresces due to ultraviolet radiation from the sun.
   c. Magnetic fields carried outward from the sun wrap around the plasma and direct it away from the sun.

3. <u>Dust tail</u>: Scatters light from the sun
   a. The yellow curved tail of the comet…
   b. Very small silicate particles up to pebble-sized bodies are blown from the coma during the outgassing process.
   c. The dust tail is curved because the pressure of sunlight differentially pushes the different sized particles. Sunlight pushes more effectively on the less massive particles than on the more massive grains.
   d. The larger grains remain in the orbit of the comet. If the comet intersects Earth's orbit, a meteor shower or stream will be the result. An example of this are the Eta Aquarids, May 6 and the Orionids on October 21, both due to the intersection of Halley's Comet orbit with the Earth's orbital path.
   e. For the most part these grains are too small to reflect sunlight because their size is near the wavelength of the light passing through them. Light is randomly bent (scattered) by these particles and some of this light is directed back to the observer allowing the tail to be seen.
   f. The dust tail of a comet is emitted in the orbital plane of the comet in the form of a sheets of material. Striations in the dust tail may be due to the rotation of the nucleus.
   g. <u>Anti-tail</u>: An illusion due to the perspective of the observer, sun, and comet that causes the dust tail to look like it is pointing towards the sun. They show the planar characteristics of the dust tail.
   h. In the Comet Wild collection mission, the particles were smaller than expected.

B. Life cycle of a comet

1. Deep-freeze state: Comet comes in from the Oort cloud as the result of a gravitational push from a passing star.
2. False initial brightening: In the region of Jupiter, the sun's energy begins to sublimate the more volatile ices such as carbon dioxide/monoxide creating a coma. These ices may be found as a thin layer on the comet's crust and within the comet's body. The comet probably appears brighter for its distance than it will on any subsequent return.
3. Water begins sublimating once the comet is inside the orbit of Mars and a large coma begins to form.
4. Tail formation: If the comet is massive enough and approaches close enough to the sun, it should develop both ion and dust tails.
    a. Ion Tail: Ionized gases and molecules (radicals) are pushed away from the sun by the solar wind. The tail is straight and glows with a blue light.
    b. Dust Tail: Outgassing from sublimating ices releases dust in a curved arc that follows the comet's orbital path. The light is forward scattered by the sun making the dust tail appear yellow in color, the same color as the sun. If the comet's orbital path crosses or comes near enough to Earth's orbit, a meteor shower may result.
5. Captured or expelled: Each future trip into the inner solar system will reduce the comet's major axis (time of revolution) until it is captured into a short period orbit or expelled forever from the solar system by the outer planets. Jupiter is most often responsible for this action.
6. Rapid loss of material: As a short period comet, each perihelion passage removes material from the comet's surface at the rate of inches to tens of feet for each perihelion passage.
7. End of the road**:** The comet may break apart and disintegrate completely, or if its orbital characteristics are correct, it may become a new member of the asteroid belt. The average life expectancy of a comet is about 1000 perihelion passes.

C. How are comets named? http://www.ss.astro.umd.edu/IAU/csbn/cnames.shtml
1. C/P/D/X—Year of discovery—Letter designating half month of discovery—Number indicating numerical order of discovery within that half month.
2. C=orbital period 200 years or greater, P-orbital period less than 200 years, D=comet disappeared, X=meaningful orbit cannot be calculated
3. Half month, numerical order: The sixth comet reported as discovered during the second half of May 2009 would be designated 2009 K6. The letters "I" and "Z" are not used.
4. C/2007 N3 (Lulin): Long period (200 years or greater orbital period) Lulin was the third comet discovered during the first half of July in the year 2007. The comet was discovered on July 11, 2007. Lulin happened to be the observatory in the country of Taiwan from which the comet was first photographed.
5. Family names:
    a. Comets are to be named for their individual discoverer(s) if at all possible. This means using the last (family) name of the discoverer(s).
    b. No more than two names of independent discoverers will try to be assigned. Sometimes, however, team names are more appropriate.

c. Family names or team names are assigned in order of discovery.
d. When a previously undiscovered comet suddenly becomes visible to dozens or even hundreds of observers at the same time such as during a total solar eclipse, it can receive a generic name such as "Great Comet" or "Eclipse Comet."

6. Examples of comet names: [C/1997 J2 (Meunier-Dupouy), 57P/du Toit-Neujmin-Delporte, 76P/West-Kohoutek-Ikemura, 105P/Singer Brewster, C/1882 R1 (Great September Comet), C/1910 A1 (Great January Comet), C/1947 V1 (Southern Comet), C/1948 V1 (Eclipse Comet), C/1977 V1 (Tsuchinshan), C/1997 B3 (SOHO), C/1999 S4 (LINEAR), C/1999 T1 (McNaught-Hartley), P/2000 C1 (Hergenrother), P/2000 Y3 (Scotti), C/1992 U1 (Shoemaker)] from the IAU International Astronomical Union nomenclature pages…

D. Astronomers who impacted our understanding of comets.

1. Tycho Brahe (1546-1601): Showed by precise measurements that the Great Comet of 1577 that it must have passed through the materials of the crystalline sphere. Since the heavens were unchangeable according to the accepted Greek philosophers this was a serious problem that needed clarification.
2. Johannes Kepler (1571-1630): Acknowledged that planets (maybe comets) orbited the sun and that their paths were ellipses, not circles. Kepler deduced that the orbital speed of a body varied with its distance from the sun—fastest when closest (perihelion) and slowest when farthest (aphelion).
3. John Flamsteed (1646-1719): Believed that the Great Comet of 1680 visible before the sun rose and then after a period of invisibility observed after sunset was the same comet.
4. Isaac Newton (1642-1727): Unified the heavens and the Earth under one set of principles by quantifying gravity. Showed that the Great Comet of 1680, seen after sunset and before sunrise, was the same comet.
5. Edmond Halley (1656-1742): Used Newton's ideas about gravity to describe the unique characteristics of an orbit, then predicted the 1758 return of a comet with similar orbital characteristics that had been seen in 1531, 1607, and 1682. The comet was first seen on Christmas Day 1758 and is today known as Halley's Comet.
6. Jan Oort (1900-1992): Because long period comets entered the inner solar system with random inclinations, Oort hypothesized that there must be a great cloud of comets at the edge of our solar system. Objects in this cloud were made to fall towards the sun or pushed away from the solar system by passing stars. Today this outer region of the solar system is known as Oort's Cloud.
7. Gerard Kuiper (1905-1973): Hypothesized a region between 30 and 50 AU from the sun, where small icy-rocky bodies and comets might exist. The volume of space at their distances from the sun was too great for them to coalesce into larger bodies. Today over 1000 rock-ice bodies have been discovered in the Kuiper Belt.
8. Fred Whipple (1906-2004): Postulated that comets were nothing more then dirty snowballs made of mostly water ice mixed with dust. When they came near to the sun their sublimating ices outgassed carrying the dust with it to form the coma,

and tail structure of comets. The spacecraft Giotto in 1986 photographing the nucleus of Halley's Comet showing Whipple's model to be correct.

E. Some famous comets
    1. Halley's Comet: It is the most famous of all comets, and it has been seen on every return since 239 BCE. Its orbit was first calculated by Edmond Halley using Isaac Newton's laws of gravity. Halley based his hypothesis upon the similar orbital characteristics of the comets of 1531, 1607, and 1682 and predicted it to return in 1758. The comet was recovered by Johann Palitzsch, a German amateur astronomer on Christmas day in 1758. It was last seen in 1986 and it is next scheduled to return in 2061. Halley's Comet has a potato-shaped nucleus 9.5 miles along its longest axis.
    2. Ikeya-Seki: The brightest comet of the 20th century. It was a sun-grazer. When it was at perihelion, Ikeya-Seki was visible in broad daylight at by covering the sun's disk with a finger. It may have been about 100 times brighter than the full moon at this point.
    3. Shoemaker-Levy 9: The first comet to crash into another world. In mid-July of 1994 with a violence that had been unanticipated by astronomers. Searches were begun by professionals to find asteroids which might one day strike the Earth.
    4. Hyakutake: Spectacular because of how close it passed the Earth (9 million miles) on March 24, 1996. It also holds the record for tail length, 355 million miles. The comet's nucleus was very small, perhaps only a mile or two in diameter.
    5. Hale-Bopp: This comet was the brightest comet seen for the longest period of time in recorded history. It was easily visible with the unaided eye from mid-winter to mid-May 1997. The next scheduled return of its 22 mile-in-diameter nucleus is in 4400 AD.
    6. 17P/Holmes: In late October of 2007 this very faint comet literally exploded as a huge vent or cave like structure collapsed and release a humongous quantity of dust and gas causing the comet to brighten over one million times and become an easy naked eye object visible from medium-sized cities.

F. Meteors and Meteorites
    1. Meteors: Shooting stars
        a. A meteor is the flash of light made by the air surrounding a small cometary dust particle entering Earth's atmosphere.
        b. Entrance velocities vary between 7-49 miles per second.
        c. As the dust particle slams into the atmosphere a column of air ionizes and fluoresces briefly creating the meteor phenomenon.
        d. Durations are from about 1/10 second to five seconds, but most are very short.
        e. Meteors related to comets can be seen when Earth's orbit comes near to the comet's path and produces an annual event known as a meteor shower.

f. Meteors related to a specific comet appear to radiate from a particular part of the sky. The meteor shower receives the name of the constellation from which the shooting stars radiate.
g. Meteoroid: The term designated for the particle in space or while it is penetrating the Earth's atmosphere.

2. Meteorites: Rocks from outer space that hit Earth another planet, moon or small solar system body.
   a. Their orbits are related to the asteroid belt and not to the orbits of comets.
   b. If their masses are between 70 pounds and 10,000 tons the Earth's atmosphere will slow them until they are in a free fall (125 mph) before they hit the Earth. The craters will be about the same size as the impacting body.
   c. Meteorites retaining a substantial part of their space velocity will produce craters tens of times larger than the diameter of the impacting body.
   d. Three basic types of meteorites
      1) <u>Stony meteorites</u>: Most common, comprising about 93.3 percent of all witnessed falls. They are divided into chondrites (containing chondrules, near spherical silicate bodies within the meteorite 2-4 mm in diameter) and achondrites (not containing chondrules). These rocks may have been found originally in the mantle of large asteroids.
      2) <u>Irons</u>: Irons make up about 5.4 percent of all falls and are composed of an alloy of nickel (normally 5-10 percent) and iron. Irons may represent the small cores of asteroids that were broken apart.
      3) <u>Stony-Irons</u> (pallasites): The rarest type of meteorite comprising about 1.3 percent of all falls. These meteorites may have originated at the core mantle boundaries of asteroid type bodies or resulted from the collisions of stony and iron meteorites.

G. Asteroids
   <u>Kirkwood gaps</u>: Regions in the asteroids belt where the orbital period of the asteroid and Jupiter are in whole number ratios.

NOTES

WORD LIST FOR COMETS AND METEORS

1. **Anti-tail:** An optical illusion created by the geometry of the Earth, sun, and comet which makes part of the comet's tail appear to point towards the sun.
2. **Aphelion:** The farthest distance that a body in an elliptical orbit can travel from the sun.
3. **Asteroid Belt:** A region of the solar system primarily found between Mars and Jupiter which contains dwarf planets and smaller solar system bodies, including defunct comets, which were unable to coalesce to form a planet because of Jupiter's gravitational presence.
4. **Coma:** The location around a comet's nucleus where the sublimating ices and dust are pushed as they begin interacting with the neighboring space environment.

5. **Comet:** A very small astronomical body which is similar to a dirty snowball (Fred Whipple). When this snowball, composed mainly of water (and small amounts of frozen carbon dioxide/monoxide, ammonia and other constituents) interacts with the sun, a fuzzy coma and long tail-like structure can result.
6. **Earth-Crossing Bodies**: Objects revolving around the sun which have orbital characteristics that might allow them to strike the Earth one day.
7. **Eccentricity:** The ovalness of an elliptical orbit, measured by the length of its major axis divided by the distance between its foci. Eccentricities must be greater than zero and less than one.
8. **Ecliptic:** The reference plane (x-axis) of the solar system created by the Earth's orbital motion around the sun.
9. **Elliptical Orbit:** A closed path which looks like an oval in higher eccentricities.
10. **Fall:** A meteorite that is witnessed to strike the Earth.
11. **Field:** A force created by a property of matter which goes beyond the boundaries of that body creating it.
12. **Fireball:** A meteor which is brighter than the planet Venus when seen during its fiery descent. They can also be called Bolides.
13. **Fluorescence:** The process by which matter gives off light by means of the excitation and recombination of electrons.
14. **Flux Line:** A location of stronger magnetic force.
15. **Focus:** The gravitational source about which an object revolves when it is in an elliptical orbit. In the case of comets this would almost always be the sun.
16. **Forward Scattered Light:** Small dust particles or molecules which are about the same size or smaller than the wavelengths of light passing through it, cannot reflect light. The particles bend the sunlight sending some of the energy back to the observer and thus allowing the dust tail to be seen.
17. **Hale-Bopp:** One of the brightest comets seen for the longest period of time in recorded history. It became visible during the late winter and continued to be visible throughout the spring of 1997.
18. **Halley's Comet:** The most famous comet in our solar system. It was the first comet predicted to return to the sun (1758) by Edmond Halley, an English astronomer.
19. **Ion Tail:** The part of a comet's tail affected by the solar wind. It is straight and points directly away from the sun as well as produces its own light through fluorescence.
20. **Inclination:** The angle which the orbital plane of an astronomical body makes to the plane of the solar system, known as the ecliptic.
21. **Long Period Comets:** Comets with orbital periods of 200 years or greater. They probably arrive from the Oort cloud since their inclinations are random.
22. **Jupiter:** It is the most massive planet in the solar system and hence it has the largest gravitational field. Jupiter is responsible for shielding the Earth from most cometary impacts, as well as capturing comets, or expelling them into deep space.
23. **Magnetic Field (sun):** A force which is created by the movement of charged particles within the sun and carries with it plasma being ejected by the sun.
24. **Major Axis:** The longest line segment of an ellipse. The major axis passes through the perihelion, center, aphelion and foci of the ellipse.
25. **Meteorite:** Space debris, not of human origin, that falls to the Earth.
26. **Meteor:** A small particle related to the dust tails of comets which slams into the Earth's atmosphere and causes a column of air about one mile in diameter to be ionized and glow.

27. **<u>Meteoroid</u>:** Pebble to dust-sized particles in orbit around the sun related to the tails of comets. The name of the solid body creating the meteor phenomenon.
28. **<u>Meteor Shower</u>:** A group of meteoroids with similar orbital characteristics that intersect the Earth's orbit on a regular basis. They originate from the dross shed by a comet's nucleus.
29. **<u>Nucleus</u>:** The small, dirty snowball part of the comet. It is usually less than 10 miles in diameter, composed mainly of water ice intermixed with dust, along with a dusty shell several inches thick.
30. **<u>Kuiper Belt</u>:** The region beyond Neptune to about 100 AUs where bodies composed of ice and rock reside. Many short period comets have their aphelions within the Kuiper Belt.
31. **<u>Oort Cloud</u>:** The farthest region of our solar system starting about 100 AUs from the sun to perhaps as distant as two light years from the sun where a halo of trillions of comets reside.
32. **<u>Perihelion</u>:** The closest distance to the sun that an astronomical object can travel in an elliptical, parabolic, or hyperbolic orbit.
33. **<u>Parabolic Orbit</u>:** An open path (eccentricity equals one) in which the sun acts as a focus but allows the comet to leave the solar system.
34. **<u>Plasma</u>:** A hot gas in which electrons have been stripped from atoms or molecules leaving electrons, ions, and radicals.
35. **<u>Radicals</u>:** The charged molecule which results after electrons have been stripped from it.
36. **<u>Short Period Comets</u>:** Comets with orbital period of less than 200 years. They generally revolve around the sun in the same direction as the planets.
37. **<u>Solar Wind</u>:** A stream of plasma being carried away from the sun by the sun's magnetic field.
38. **<u>Sublimate</u>:** The process by which a solid changes directly into a gas without going through the liquid phase.
39. **<u>Sun-grazer</u>:** A comet that has its perihelion position very near to or beneath the sun's photosphere. In the latter case the comet never makes it around the sun.
40. **<u>Tail</u>:** The regions stretching behind the coma of a comet where dust particles are pushed away by light pressure from the sun and the solar wind interacts with the plasma being generated by the sun's ultraviolet radiation.
41. **<u>Ultraviolet Radiation</u>:** A part of electromagnetic spectrum where energies are greater than visible light and less than X-Rays. Ultraviolet radiation ionizes atoms and molecules.
42. **<u>Volatiles</u>:** Substances with low melt and boil temperatures.
43. **<u>Volume</u>:** The amount of space occupied by a three-dimensional object (Webster).
44. **<u>Zodiacal Light</u>:** A region of the sky centered on the ecliptic and the sun where forward scattered light illuminates extremely small dust particles during the time before dawn and after dusk.

Name ________________________________ Date ________________ Moravian University

DISTILL THE DEFINITION TO ITS BASIC MEANING

Instructions: Take the word on the left and find the most important information, words, or numbers associated with it to complete a shortened definition on the right. **You may not use anymore than six words for your core definition**. **Abbreviations will count as words,** such as mi./sec., equals miles/second, equals two words. Numbers, symbols, and punctuation will not count as words unless used incorrectly. Here is an example. "2 b or not 2 b" will mean "To be or not to be," and will have six words, not four. The grammar police will also be arresting you!

Word	Most Important Core Words
Anti-tail	
Aphelion	
Asteroid Belt	
Coma	
Comet	
Earth-Crossing Bodies	
Eccentricity	
Ecliptic	
Elliptical Orbit	
Fall	
Field	
Fireball	
Fluorescence	
Flux Line	
Focus	
Forward Scattered Light	
Hale-Bopp	
Halley's Comet	
Ion Tail	
Word	Most Important Core Words

Inclination	
Long Period Comets	
Jupiter	
Magnetic Field	
Major Axis	
Meteorite	
Meteoroid	
Meteor Shower	
Nucleus	
Kuiper Belt	
Oort Cloud	
Perihelion	
Parabolic Orbit	
Plasma	
Radicals	
Short Period Comets	
Solar Wind	
Sublimate	
Sun-grazer	
Tail	
Ultraviolet Radiation	
Volatiles	
Volume	
Zodiacal Light	

Can You Identify which of the Following Orbits Represent Comets Halley?

GENERAL CATALOG

Comet	T	q	e	P	Peri.	Node	Incl.	Epoch
-239	39 May 25.12	0.5854	0.967	76.7	88.10	30.10	163.46	39 June 7
-163	63 Nov. 12.57	0.5845	0.967	76.9	89.10	31.35	163.70	63 Nov. 15
-146	46 June 28.0	0.43	1.0		261	329	71	
- 86	86 Aug. 6.462	0.58561	0.967	77.1	90.764	33.306	163.335	86 Aug. 23
- 11	11 Oct. 10.849	0.58720	0.967	76.3	92.544	35.191	163.584	11 Oct. 8
66	66 Jan. 25.960	0.58510	0.967	76.5	92.637	35.416	163.572	66 Feb. 6
141	41 Mar. 22.434	0.58314	0.967	77.2	93.678	36.506	163.433	41 Mar. 24
218	18 May 17.723	0.58147	0.967	77.4	94.132	37.194	163.569	18 Apr. 29
240	40 Nov. 10	0.371	1.0		82	213	44	
295	95 Apr. 20.398	0.57591	0.968	79.1	95.226	38.398	163.363	95 Apr. 25
374	74 Feb. 16.342	0.57719	0.968	78.8	96.494	39.865	163.538	74 Mar. 1
390	90 Sept. 5	0.92	1.0		23	355	36	
400	00 Feb. 25	0.21	1.0		47	37	32	
442	42 Dec. 15	1.53	1.0		178	270	106	
451	51 June 28.249	0.57374	0.968	79.3	97.011	40.496	163.475	51 June 25
530	30 Sept.27.130	0.57559	0.968	78.9	97.565	41.260	163.390	30 Oct. 8
539	39 Nov. 6	0.16	1.0		246	32	19	
565	65 July 15.0	0.832	1.0		79	179	121	
568	68 Aug. 27.7	0.87	1.0		35	301	4	
574	74 Mar. 25	0.73	1.0		342	154	54	
607	07 Mar. 15.476	0.58083	0.968	77.5	98.782	42.546	163.472	07 Mar. 18
684	84 Oct. 2.767	0.57958	0.968	77.6	99.132	43.085	163.413	84 Sept.29
760	60 May 20.671	0.58184	0.967	77.0	99.980	43.972	163.439	60 June 2
770	70 June 5.8	0.58	1.0		88	110	117	
837	37 Feb. 28.270	0.58232	0.967	76.9	100.084	44.215	163.443	37 Mar. 10
868	68 Mar. 4	0.42	1.0		277	320	65	
905	05 Apr. 26	0.20	1.0		50	69	140	
912	12 July 18.674	0.58016	0.968	77.4	100.759	44.931	163.307	12 July 14
961	61 Dec. 28	0.63	1.0		85	1	119	
989	89 Sept. 5.688	0.58191	0.967	77.1	101.466	45.845	163.395	89 Aug. 19
1014	14 Apr. 6.0	0.56	1.0		84	173	117	
1018	18 Aug. 27	0.62	1.0		197	184	35	
1066	66 Mar. 20.934	0.57450	0.968	79.3	102.455	46.909	163.108	66 Mar. 8
1080	80 Sept.10.94	0.6809	1.0		73.63	322.20	6.89	
1092	92 Feb. 22	0.77	1.0		62	113	124	
1097	97 Sept.22.3	0.302	1.0		298	351	41	
1110	10 May 18.0	0.83	1.0		358	320	136.5	
1132	32 Aug. 30.70	0.7355	1.0		114.2	212.5	106.3	
1145	45 Apr. 18.561	0.57479	0.968	79.0	103.686	48.338	163.220	45 Apr. 2
1147	47 Jan. 28	0.12	1.0		300	281	110	
1222	22 Sept.28.823	0.57421	0.968	79.1	103.831	48.588	163.188	22 Oct. 15
1230	30 Dec. 28.8	0.86	1.0		181	303	16	
1240	40 Jan. 21.56	0.6677	1.0		331.4	134.4	75.3	
1245	45 Apr. 1	0.50	1.0		87	179	20	
1264	64 July 20.29	0.8249	1.0		159.70	150.35	16.40	
1293	93 Oct. 28	0.78	1.0		313	88	30	
1299	99 Mar. 31.81	0.31793	1.0		103.88	116.24	111.01	
1301	01 Oct. 25.582	0.57271	0.968	79.1	104.482	49.436	163.072	01 Nov. 9
1305	05 Jan. 19	0.65	1.0		56	105	99	
1337	37 June 14.85	0.749	1.0		79.6	96.9	143.6	

MAKE A COMET

The nuclei of comets are composed of common items such as water, carbon dioxide, ammonia, silicate grit, and some more exotic organic materials. All of these items are readily accessible from grocery or hardware stores. Dry ice, which is frozen carbon dioxide, can be purchased usually from a company that sells and ships ice cream products.

Materials and ingredients to ensure a successful comet:

1. A gallon of water in a plastic container
2. Dry ice—frozen carbon dioxide (between 5-10 pounds). It's -110º F. Handle with care.
3. Ammonia—a few drops or squirts from a spray applicator for cleaning glass that contains ammonia.
4. Dirt/potting soil (organics), about one handful—smash all of the clumps.
5. Sand—larger silicate particles that could one day become meteors streaking through the Earth's atmosphere.
6. Large bowl lined with newspaper. The newspaper helps insulate the plastic.
7. Plastic bucket on which to display the comet nucleus when it is completed.
8. Several thick garbage bags.
9. Scissors to cut down garbage bag to make it more manageable in the bowl.
10. Several large cloth towels.
11. Roll of paper towels—It is a messy process to make a comet.
12. Rubber mallet or hammer.
13. Thick heavy duty work gloves.

Recipe for a comet's nucleus:

1. Place the plastic garbage bag in the bowl lined with newspaper.
2. Add about 1/3 gallon of water to which will be added the ammonia (several drops or squirts), and a handful of dirt, plus a handful of sand. Knead the bag from underneath to mix the ingredients.
3. Put between three and five pounds of dry ice onto a cloth towel on the floor. Fold the towel over itself and hammer away until the dry ice is pulverized.
4. With gloves on, add the dry ice to the mixture in the bowl, knead well from underneath until the material begins clumping together to form the comet nucleus. There will be lots of condensed water vapor escaping from the bag, hissing sounds, and sometimes even a "pop" as the nucleus acts very much like the real thing.
5. Remove the comet from the bag, pour a little water over the ice to form a crust, and set the comet nucleus on an inverted plastic bucket for examination. The comet should continue hissing. Occasional popping activity should occur as sublimating carbon dioxide pushes through the thin ice crust. Safety goggles are recommended.

Outgassing activity in a comet's nucleus: Take a plastic film canister with a plastic snap lid. Place several pieces of dry ice into it and secure the lid. Leave the canister on a lab table and wait for about one minute. The sublimating carbon dioxide in the container will create enough pressure to pop the lid four to six feet into the air.

CAN YOU ANSWER THE FOLLOWING QUESTIONS/STATEMENTS ABOUT SMALL SOLAR SYSTEM BODIES

COMETS IN GENERAL

1. Comets have played an important role in the history and evolution of astronomical thought. To the Greeks, they were "hairy stars," a phenomenon occurring in the Earth's ________________. Tycho Brahe (1546-1601) showed that comets belonged to the realm of the __________________. Isaac Newton (1642-1727) explained their ___________________ based upon the universal law of gravitation, while Edmond Halley (1656-1742) proved that comets could make repeated returns to the ________________.

2. A comet has been called the closest thing to nothing that anything can be and still be considered something. Although not a good definition for a comet, it is a true statement. Why? ____
____

3. Comets may represent the best example of the original, undifferentiated material left over from the formation of the solar system. In those early days these bodies may have been catapulted into the outer fringes of the solar system from the gravitational effects of the planets ________________ and ________________ working in concert with **U**______________ and **N**______________. These outer planets may have driven the cometary bodies inward towards the sun.

4. Supposedly, in the outer reaches of our solar system there is a large region of several trillion comets known as the ________________ cloud.

5. ________________ moving near this cloud can cause some of these comets to fall in towards the ________________ where the major planets eventually expel or modify their long period orbits into orbits of shorter duration.

6. New comets entering the solar system for the first time have random inclinations (tilts) to the plane of the ecliptic indicating that the shape of the Oort cloud is ________________.

7. Comets which have orbital periods of 200 years or greater are termed ________________ period comets, while comets with orbital periods of less than 200 years are called ________________ period comets.

8. As a class of objects in the solar system, comets with periods of less than 200 years have orbital eccentricities and inclinations which are, on average, much larger than the ________________. However, almost all of these comets revolve around the sun in the same ________________ as the planets, indicating the overpowering influence that the giant planets have had on these objects. Halley's Comet is one of the exceptions to this rule.

9. Comets with orbital motions that were originally clockwise* were either ________________ from the solar system by the Jovian** planets or were gravitationally perturbed to orbit the sun in a ________________ direction.

   *The planets revolve around the sun in a counterclockwise direction.
   **Jupiter, Saturn, Uranus, and Neptune

MORPHOLOGY OF A COMET

10. A comet approaching the sun can be likened to a dirty ________________. It is mainly composed of frozen ________________ mixed with ________________. Other constituents include frozen **m**_______________, **a**________________, and **c**_________ **d**_________**.**
.
11. The smallest part of the comet, described in the preceding question as the dirty snowball, is called the ________________. A typical diameter may be ________________ miles. Comet Hyakutake, which appeared in the spring of 1996 had a nucleus less than two miles (1-3 km) in diameter. Hale-Bopp, which was very prominent during the spring of 1997 has a nucleus as great as 22 miles (45 km) in diameter. It is generally thought that the "snowball" part of the comet is coven with a crust of ________________ several inches thick.

12. As sunlight heats the comet, the ices ________________, (change directly into a gas). Pockets of gas form underneath the comet's crusty material in response to the solar warming. When these areas "pop," the escaping gasses drag dust and other gritty substances away from the nucleus to form the ________________, the cloudlike region surrounding the solid center.

13. This region around the nucleus, which may be hundreds of thousands of miles in diameter, is composed of neutral gases, some **p**________________ and **d**________________. Collectively, the coma and nucleus of a comet are referred to as the comet's ________________.

14. Surrounding the coma and even part of the tail is a larger invisible cloud or halo of excited ________________ gas which can be millions of miles in extent. This cloud also suggests that one of the primary constituents of a comet's nucleus is a very common compound called ________________. This was confirmed by the Halley flybys of 1986.

15. As a comet approaches the sun ________________ (type of energy) radiation excites the gases in the coma until they begin to glow or **f**________________. In this process, energy of a shorter wavelength, which is invisible to the human eye, is absorbed by the gases of the comet and emitted as longer wavelengths, which can be seen. Comets generate their own light.

16. The mechanism which creates one of the two types of tails a comet may possess involves the solar wind and the magnetic field of the sun. The solar wind (plasma) slams into the plasma surrounding the coma. This produces a shock front (a region of higher density) because the velocity of the solar wind is reduced. The result is a pileup of other solar wind particles in the region. This forces the magnetic field lines of the sun to wrap themselves around the coma to form the **i________________** tail. This tail is usually STRAIGHT/CURVED (circle one) and YELLOW/BLUE (circle one) in color.

17. Meanwhile, ________________ escaping the nucleus is carried into the coma by the jetting action of the gasses which are escaping from the warmed nucleus. The velocities of the particles are modified by the flow of these gases and may even be coupled to the magnetic field sweeping around the comet. The pressure of sunlight also pushes smaller particles, one micron or less in diameter, in back of the nucleus to form the ________________ tail which is shining through the process of **s________________** **(**reflected) light. This tail is usually STRAIGHT/CURVED (circle one) and YELLOW/BLUE (circle one) in color.

18. When light is ________________, the rays which are passing the small particles of dust are deflected (bent) from their straight line paths. Dust particles which are about the same size or smaller than the sunlight passing through them cannot ________________ sunlight. Some of this bent light reaches us to reveal the location of the dust tail. This is different from __________________ light which allows a particle to be viewed directly.

19. The beautiful blue tail that Hyakutake produced during the latter part of March 1996 was an excellent example of an ________________ tail. Hyakutake was a dust poor comet.

20. With respect to direction, a comet's tail always points TOWARD/AWAY (circle one) from the sun. When a comet enters the solar system, it comes in _________________ first and __________________ second. However, when a comet leaves the solar system, it exits __________________ first and __________________ second.

DISCOVERING A COMET

21. Due to satellite imaging and ground-based surveys ________________ of comets are discovered each year. Because they are generally faint, diffuse objects when first seen, WIDE FIELD/NARROW FIELD (circle one) telescopes and cameras are usually employed in cometary searches. Because new comets can be found in any part of the sky, and searching for them can be a very time-consuming enterprise, AMATEUR/PROFESSIONAL (circle one) astronomers in the past have played a significant role finding new comets. Since most comets are brightest when near perihelion, they are generally discovered in the vicinity of the ________________. Therefore, a good time to go out and search for comets would be before ________________ or after ________________.

22. Once a comet is discovered it is named after the _______________(s) who discovered it. The family names of as many as ONE/TWO/THREE (circle one) people can be attached to the object.

23. Within several days after discovery an _______________ is calculated. This gives astronomers the ability to describe the path of the comet within the framework of the solar system bodies and in what part of the sky it will be seen from Earth.

BRIGHTNESS OF A COMET

24. Once this is completed the brightness or _______________ of the comet at different distances from the Earth can be calculated.

25. The difference in intensity between one whole magnitude is _______________. The brighter the comet, the more POSITIVE/NEGATIVE (circle one) the magnitude of the object.

26. Determining the brightness of a comet is a difficult task to accomplish because the comet produces light through two processes: _______________ and _______________.

27. The change in brightness of a comet due to its distance from the _______________ varies as the inverse square of this distance ($^{1}/_{d^2}$). This means that if the distance of the comet is halved, the brightness of the comet will increase _______________ times.

28. The change in brightness of the comet due to its distance from the _______________ is another matter. As its distance is halved the comet's brightness can increase by ($^{1}/_{d^2}$) to ($^{1}/_{d^6}$), or from _______________ to _______________ times. This can make a huge difference as to whether the comet becomes spectacular or is a dud.

29. Many times comets arriving from the Oort cloud for the first time may have a layer of easily sublimed volatiles which cause the comet to appear abnormally _______________ for its distance away from the sun. One of the most overrated comets to fit this scenario was Comet Kohoutek of 1973-74. On the other hand, Hyakutake blossomed into beautiful object in 1996, as well as Comet Hale-Bopp (spring 1997). and Comet McNaught (January 2007).

30. The end result of a comet may be the total disintegration of the object or the exhaustion of all volatiles and the misinterpretation of this body for an _______________.

METEORS

31. Over tens of thousands of years, the _______________ from the tails of comets gradually disperses as a result of the _______________ perturbations (tugs and pulls) of the planets and the slowing of their orbital velocities due to the *Poynting-Robertson effect. In the latter situation, rotating dust particles absorbs energy in the sunward direction, and radiate infrared energy back into space more effectively in the direction opposite to its orbital motion. This slows the velocity of the dust, causing the particles to eventually ________________ into the sun.

32. If a dust particle from a comet's tail enters the atmosphere of the Earth, a _______________ is the result.

33. The streak of light which is seen in the sky IS/IS NOT (circle one) a result of the glow of the dust particle itself.

34. The very rapid motion (7-45 miles/second or 11-72 km/sec) of the particle through the atmosphere causes the cylinder of air through which the particle is passing to _______________ revealing the location of the particle. The actual object disintegrates and/or is vaporized in the process. Beyond 45 miles per second (72 km/sec) the object is moving too fast to be a part of the solar system. Seven miles per second (11 km/sec) represents the escape velocity of Earth and the lower limit of meteor velocities.

35. When a meteor is observed, the event is usually occurring at an altitude of 5-10 / 10-40 / 40-70 (circle one) miles above the Earth's surface.

36. At certain times of the year an observer may view, over a period of several hours, numerous meteors radiating from the same location in the sky. At these times the Earth's orbital plane is intersecting the orbital plane of a _______________. These events are called ____________________ (two words).

37. The fact that meteors appear to be diverging from a _______________ indicates that the particles are traveling ________________ to each other. As they approach the observer they _______________, similar to what a person would expect if she/he were standing on a long, straight section of railroad tracks which stretched in front of the viewer to a vanishing point.

38. An extremely bright meteor is usually referred to as a _________________.

39. A dust or rock fragment in orbit about the sun is referred to as a _________________. If it is much larger the term _________________ would apply.

40. Objects which enter the atmosphere and strike the Earth or other planets or moons are called ________________. No fireball from a meteor shower has ever been witnessed to fall to Earth. Therefore it is assumed that meteors originate from _________________ while the natural objects that fall to Earth to become meteorites originate in the

________________________ (two words) between __________________ and ___________________ (the name of two planets).

METEORITES

41. There are three broad classifications of meteorites which are as follows: __________________, __________________, ___________________.

42. The most common variety, called __________________, are basically composed of __________________ material intermixed with varying amounts of iron in the form of flecks. They may or may not have inclusions called **ch**________________ composed usually of olivine and pyroxene, silicate minerals with higher concentrations of iron and magnesium. If these meteorites have these inclusions they are called **ch**______________; if not, they are termed **a**________________.

43. __________________ meteorites are composed primarily of an alloy of iron-nickel with up to 13 percent nickel mixed throughout. Although this type of meteorite is not commonly the type recovered from a witnessed fall, they are the predominate meteorites associated with finds because they ____ ____

44. The fact that stony and iron meteorites exist, indicates that the parent bodies to which these specimens originally belonged probably had silicate crusts and iron cores. In other words, these objects were chemically ________________.

45. The least common variety, called ________________, are composed of a mixture of silicates and native iron which probably originated from the transition zone of a body that was differentiated, or from the collisions of two different types of asteroids, or an undifferentiated body.

46. All meteorites are about ________________ years of age, indicating that they are examples of unchanged original solar system material.

47. Meteorites as a whole are an excellent indicator of the original bulk _______________ of the terrestrial* bodies in the solar system. Stony meteorites give geologists insight into the original bulk composition of planetary ________________. *The four inner planets

48. The orbital velocities of small meteorites (70 lbs to 10,000 tons) striking the Earth's surface are FULLY/NOT FULLY (circle one) slowed to a free fall by the Earth's atmosphere. Giant meteorites strike the Earth at velocities of FEET PER SECOND/MILES PER SECOND (circle one).

49. When a large meteorite strikes the Earth or another astronomical body a _______________ is formed which is BIGGER THAN/AS BIG AS (circle one) the impacting body. The kinetic energy (energy of motion) of the meteorite is converted into _______________ which vaporizes the original meteorite and the ground in the immediate target zone. The impact event looks very much like a rock being tossed into a _______________.

50. The floor of the meteorite crater is always _________________ than the surrounding terrain. The crater walls are always _________________ than the surrounding terrain.

51. The best example of a meteorite crater in the world is found near Winslow, Arizona and is called ________________________. The crater is PROPERLY/IMPROPERLY named (circle one). By car, Winslow is about three hours southeast of the south rim of the Grand Canyon and about one hour east of Flagstaff, AZ. The event which formed this crater occurred about 50,000 years ago.

NOTES

ANSWERS TO SESSION TWELVE QUESTIONS

COMETS IN GENERAL

1. atmosphere, planets (solar system), orbital motions, sun
2. While the comet's nucleus, which is ultimately responsible for the cometary shape is only miles in diameter, the comet's tail and coma are spread over a huge volume of space.
3. Jupiter, Saturn, Uranus, Neptune
4. Oort
5. stars, sun
6. spherical
7. long, short
8. planets, direction
9. ejected, counterclockwise

MORPHOLOGY OF COMETS

10. snowball, water (ice), dust, methane, ammonia, carbon dioxide
11. nucleus, less than one mile to 40 miles, dust/sandy material
12. sublime, coma
13. plasma, dust, head
14. hydrogen, water
15. ultraviolet, fluoresce
16. ion (plasma), STRAIGHT, BLUE
17. dust, dust, scattered, CURVED, YELLOW
18. scattered, reflect, reflected
19. ion
20. AWAY, head, tail, tail, head

DISCOVERING A COMET

21. hundreds, WIDE FIELD, AMATEUR, sun, sunrise, sunset (in dark skies)
22. individual (s), TWO
23. orbit

BRIGHTNESS OF A COMET

24. magnitude
25. 2.51, NEGATIVE
26. fluorescence, scattering
27. Earth, 4
28. sun, 4, 64
29. bright
30. asteroid

METEORS

31. dust, gravitational, spiral
32. meteor (shooting star)
33. IS NOT

34. ionize (fluoresce)
35. 40-70
36. comet, meteor showers
37. radiant, parallel, diverge
38. fireball (bolide)
39. meteoroid, asteroid
40. meteorites, comets, asteroid belt, Mars, Jupiter

METEORITES

41. irons, stony-irons, stones
42. stones, silicate, chondrules, chondrites, achondrites
43. iron (siderites), are easy to find with metal detectors and weather more slowly
44. differentiated
45. stony-irons
46. 4.5 billion (5 billion)
47. composition, mantles
48. FULLY, MILES PER SECOND
49. crater, BIGGER THAN, heat, liquid
50. lower, higher
51. Meteor Crater, IMPROPERLY

NOTES

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